

Laser Upgrade
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Upgrade Workshop for
**Accelerator
Test Facility II**

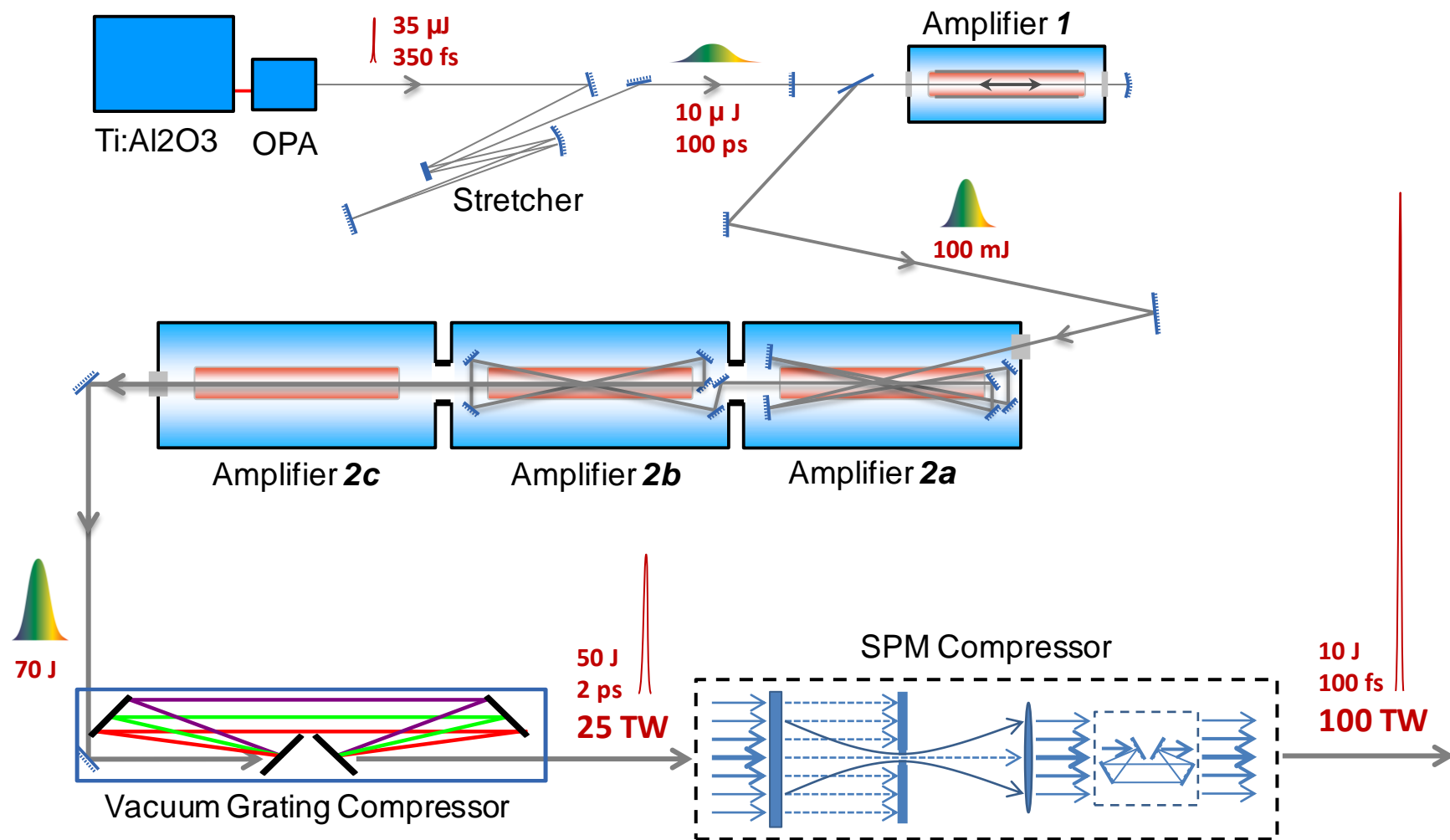
Laser systems at ATF II

- 100 TW CO₂ Laser Upgrade
- RF Photocathode Gun Drive Laser
- RF Photocathode Gun Pulse Train Laser
- NIR Strong Field Laser

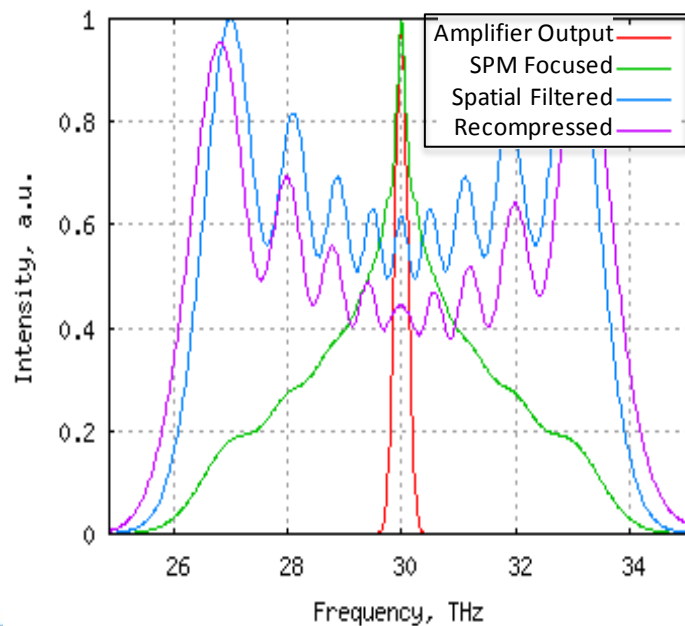
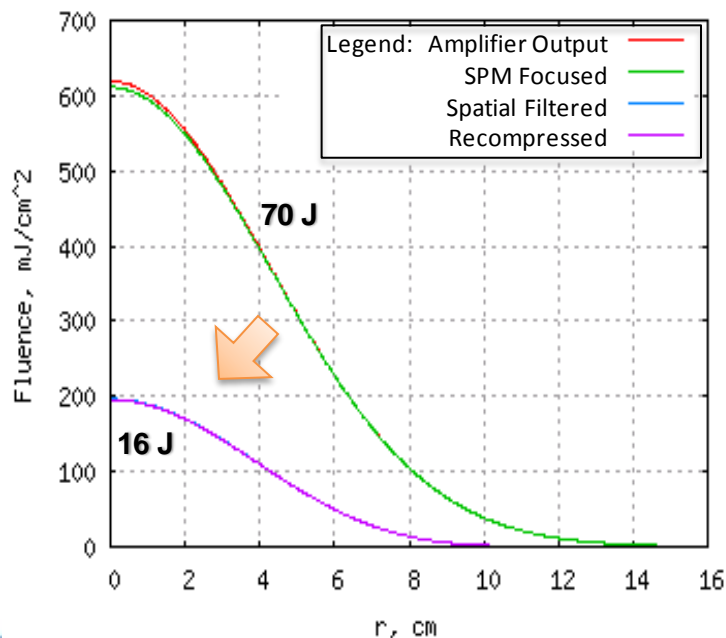
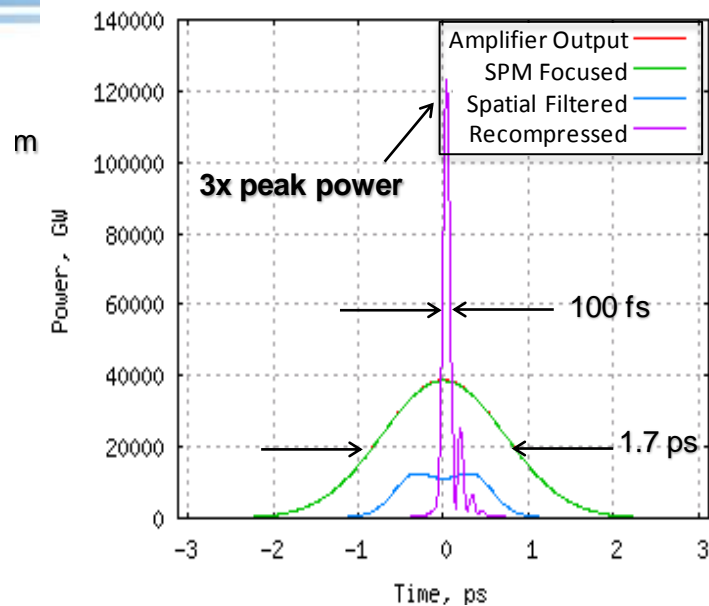
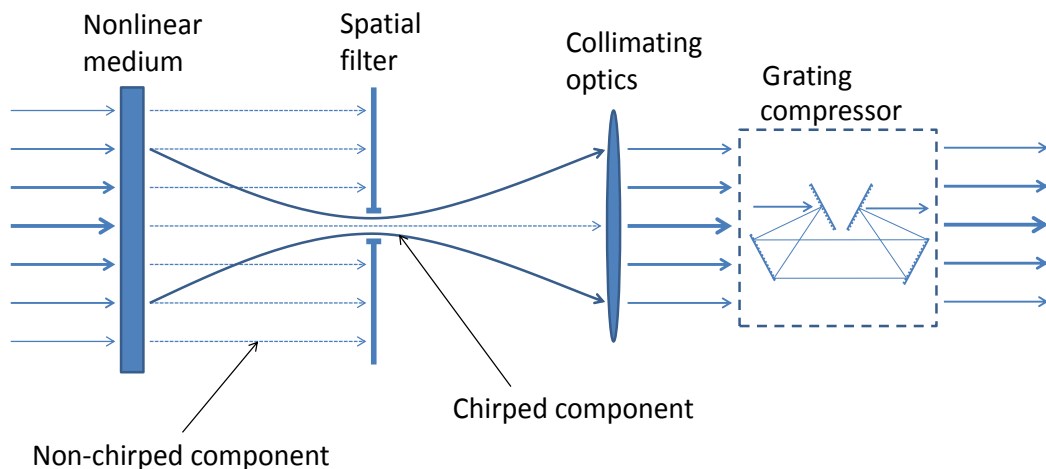
100-TW CO₂ Laser Progress

- Solid-state (QPM) seed-pulse generator **Done** 2-3 TW - 2 ps
- Chirped-pulse amplification **In tests** 5-10 TW
- New (isotonic) main amplifier **RFQ sent** 25 TW
- Nonlinear pulse compressor **R&D** 100 TW - 100 fs

100 TW CO₂ Laser System Schematic

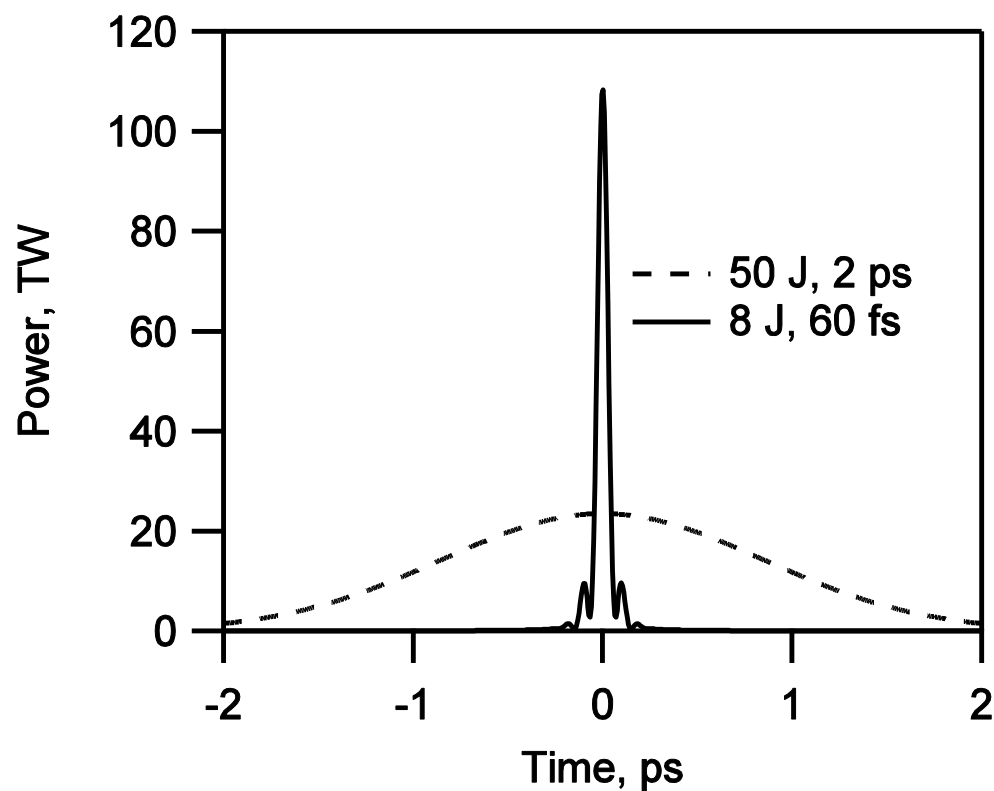


Simulations of SPM Compression

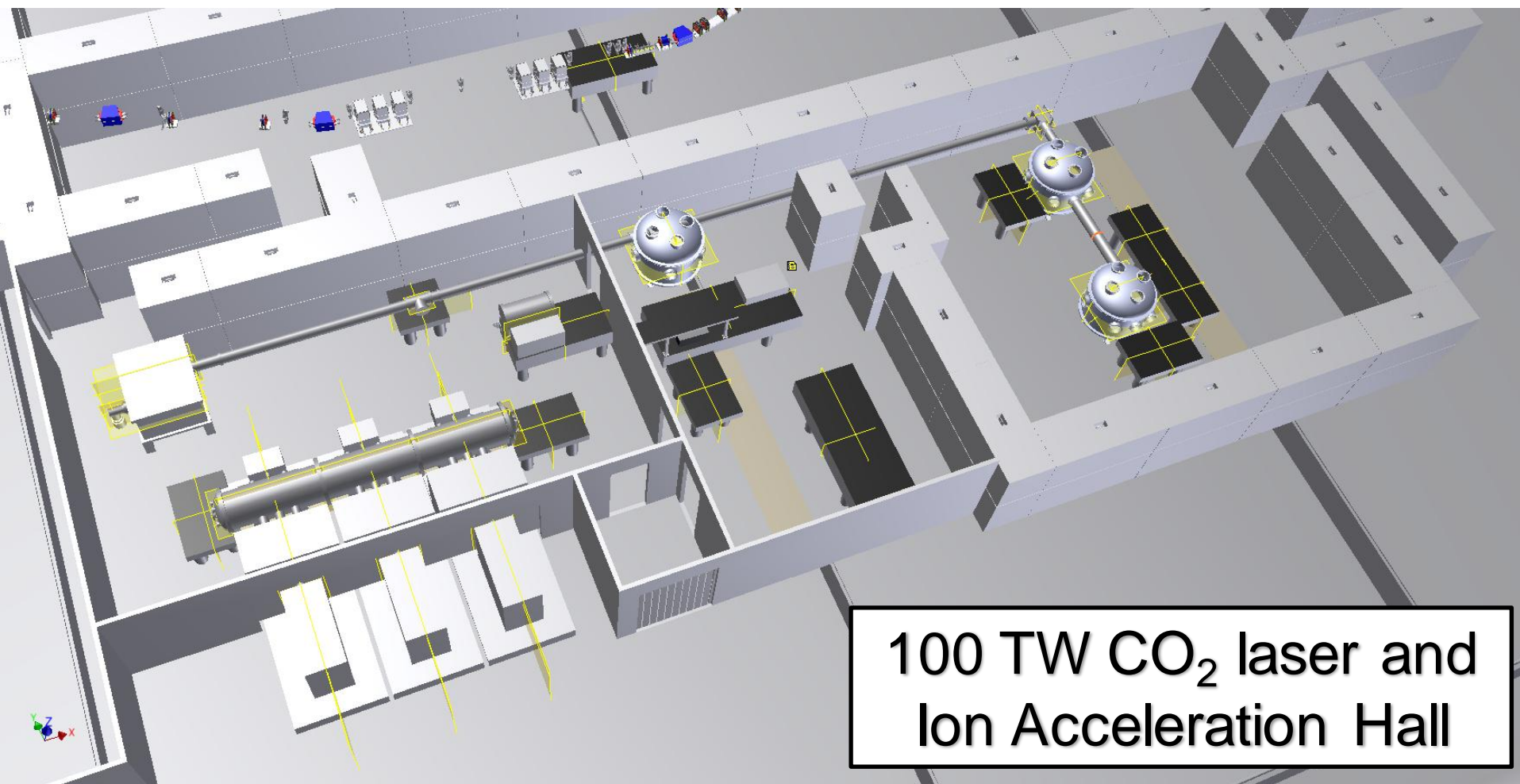


Non-linear Compression

- Numerical optimization progress:



CO₂ Laser: Location at ATF II



100 TW CO₂ laser and
Ion Acceleration Hall

Gun Drive Laser: Overview



Amplifier footprint: 1x1.5 m²

- Commercial Ti:Sapphire system with current support available from vendor
- Has been commissioned, awaiting seed oscillator to become fully operational
- Basic parameters for Ultrafast Electron Diffraction experiment already demonstrated
- ATF II Linac operational parameters nearly achieved
- Spatial and temporal shaping still to be implemented

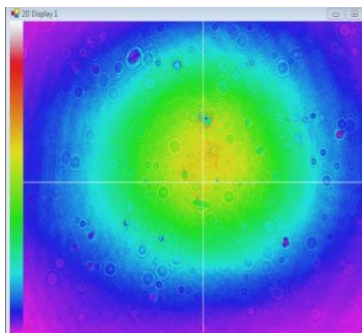
Gun Drive Laser:

Commonality w/CO₂ Seed System

- Same seed oscillator, pump lasers, amplifier & electronics
- Followed by different nonlinear stages (OPA vs. THG)
- Duplication of systems allows for reduced spare parts requirements
- One system can be used as donor to get other system through major component failures
- Operational experience benefits both systems

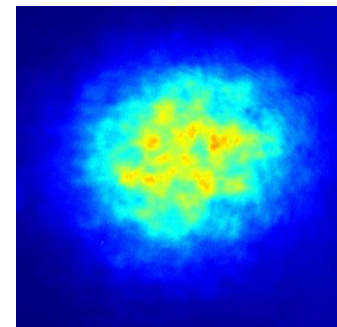
Gun Drive Laser: Current Performance

- Amplifier and THG working with shared seed oscillator
- Second oscillator being upgraded for improved pointing stability
- 2nd Phaselocking system not yet built; but, can quickly duplicate previous electronics



IR Spatial
Distribution

IR Pulse Duration	170 fs
Repetition Rate	240 kHz
Pulse Energy	7 mJ
Stability	<2% RMS
Beam profile	$M^2 < 1.5$

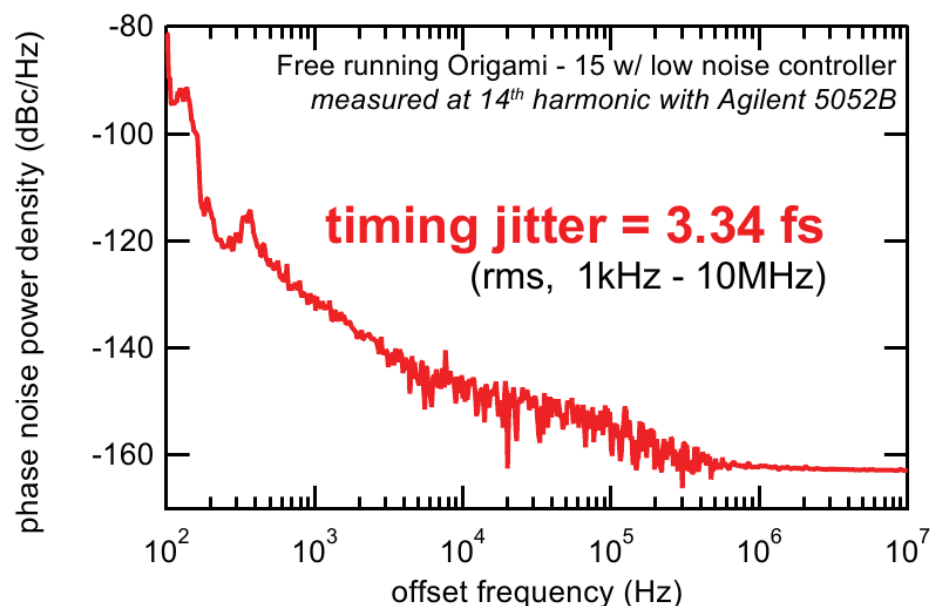


UV Spatial
Distribution

Gun Drive Laser: Synchronization

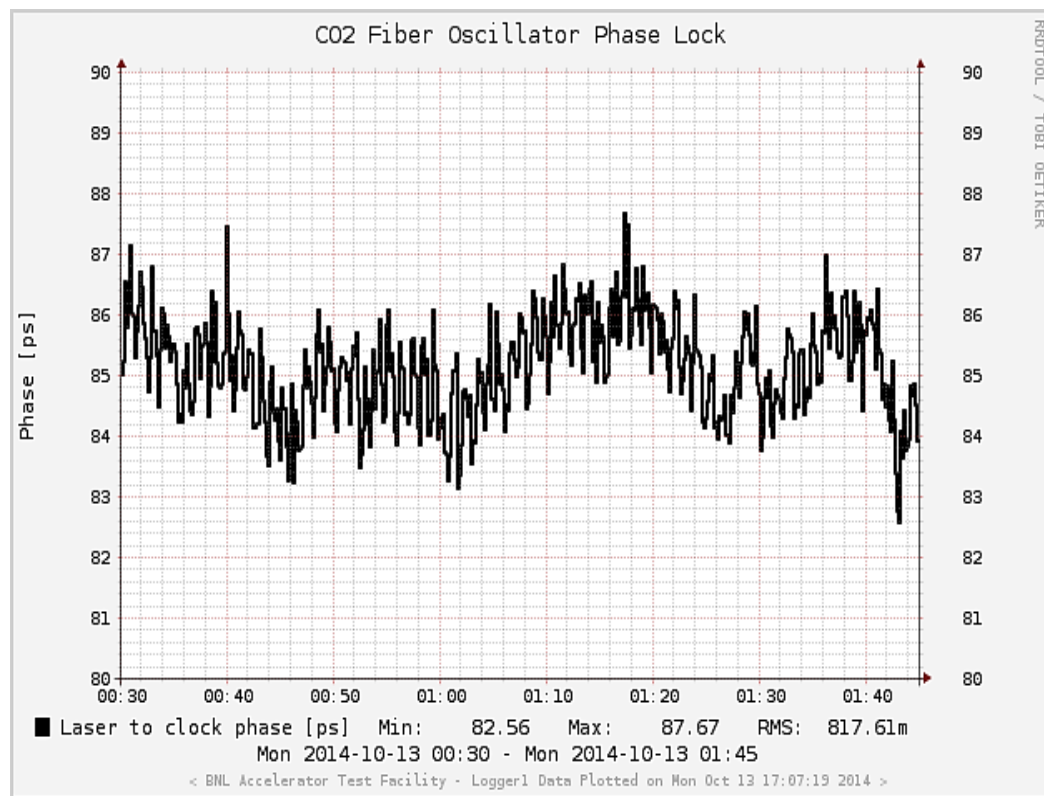
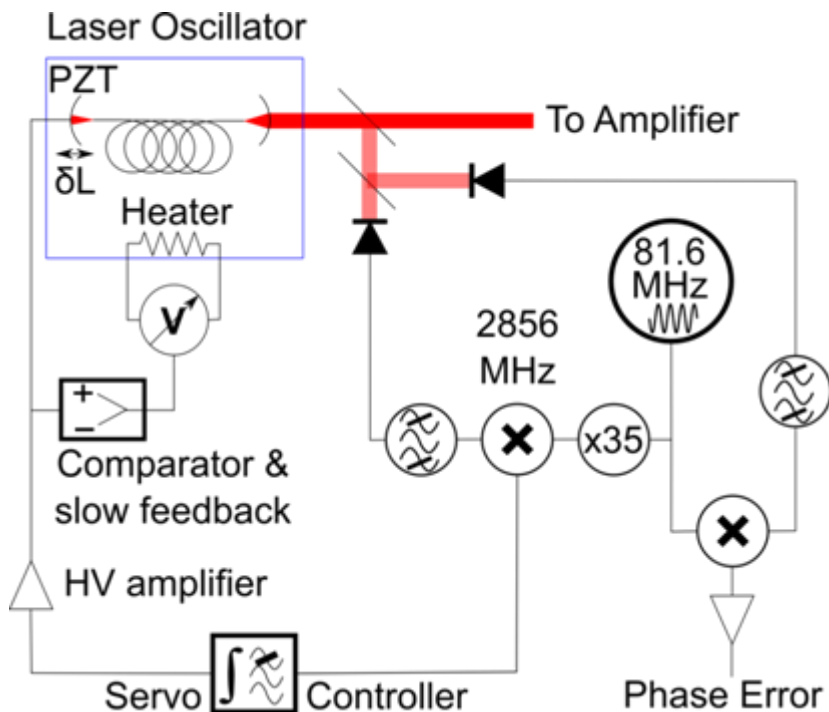
- Fiber-based seed oscillator (One-Five GmbH Origami-08) has very low free-running timing jitter
- Lower environmental sensitivity than free-space oscillator cavities

Phase noise / timing jitter



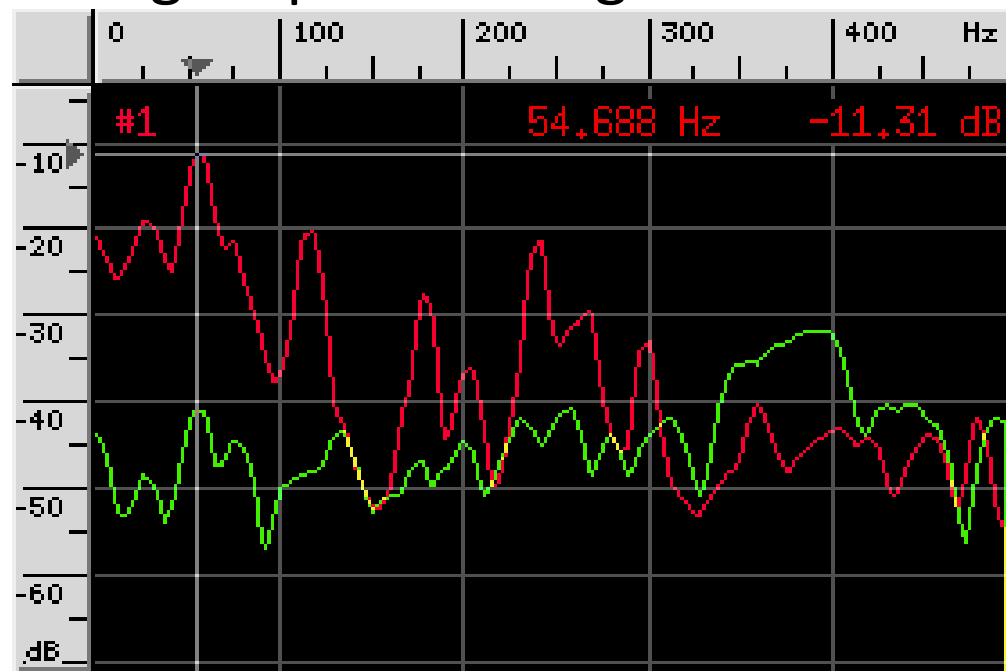
Synchronization 2

- Phase-locking system assembled in-house from commercial hardware
- System has proven reliable at 1 ps level of jitter, few ps level of slow drift



Drive Laser: Synchronization Improvement

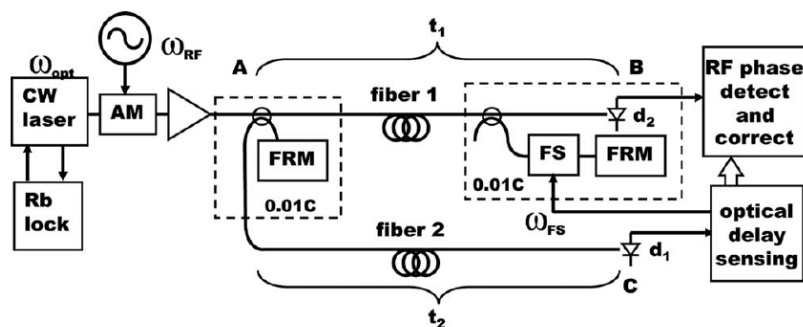
- Beginning to identify challenges to improve timing stabilization
- Length of laser transport=50 m
- Stability desired: $\sim 10\text{fs} = 3\text{ }\mu\text{m} = 60 \times 10^{-9} \Delta L/L$
- Ground transmission and building response being measured
- Laser acoustic coupling being measured:
- Resonances, enclosure, ambient noise all to be addressed



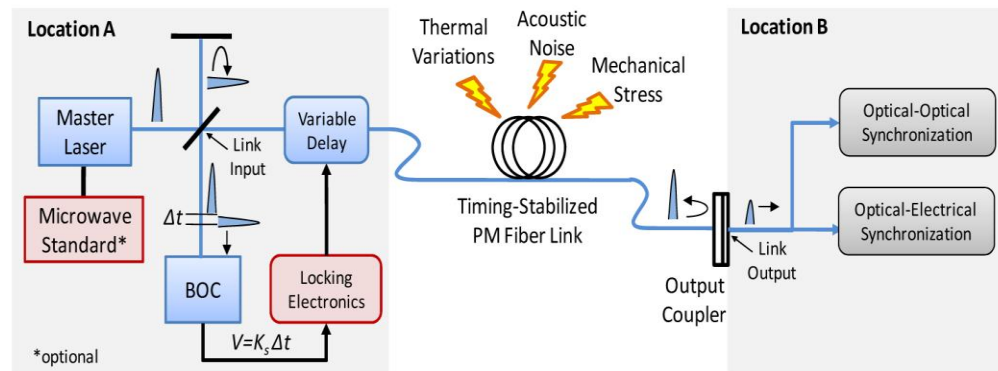
Resultant phase error versus acoustic noise frequency

Drive Laser: Synchronization to <10 fs

- R. Wilcox gave overview yesterday of approaches to take for few fs synchronization
- Stabilized optical timing distribution loops will be needed:



R. Wilcox, et al



Peng et al, "Long-term stable, sub-femtosecond timing distribution via a 1.2-km polarization-maintaining fiber link: approaching 10 link stability," Opt. Express **21**, 19982-19989 (2013);
<http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-21-17-19982>

- Limits of existing ATF phase-locking electronics need to be better characterized
- New beam arrival monitors may be needed to measure e-beam jitter

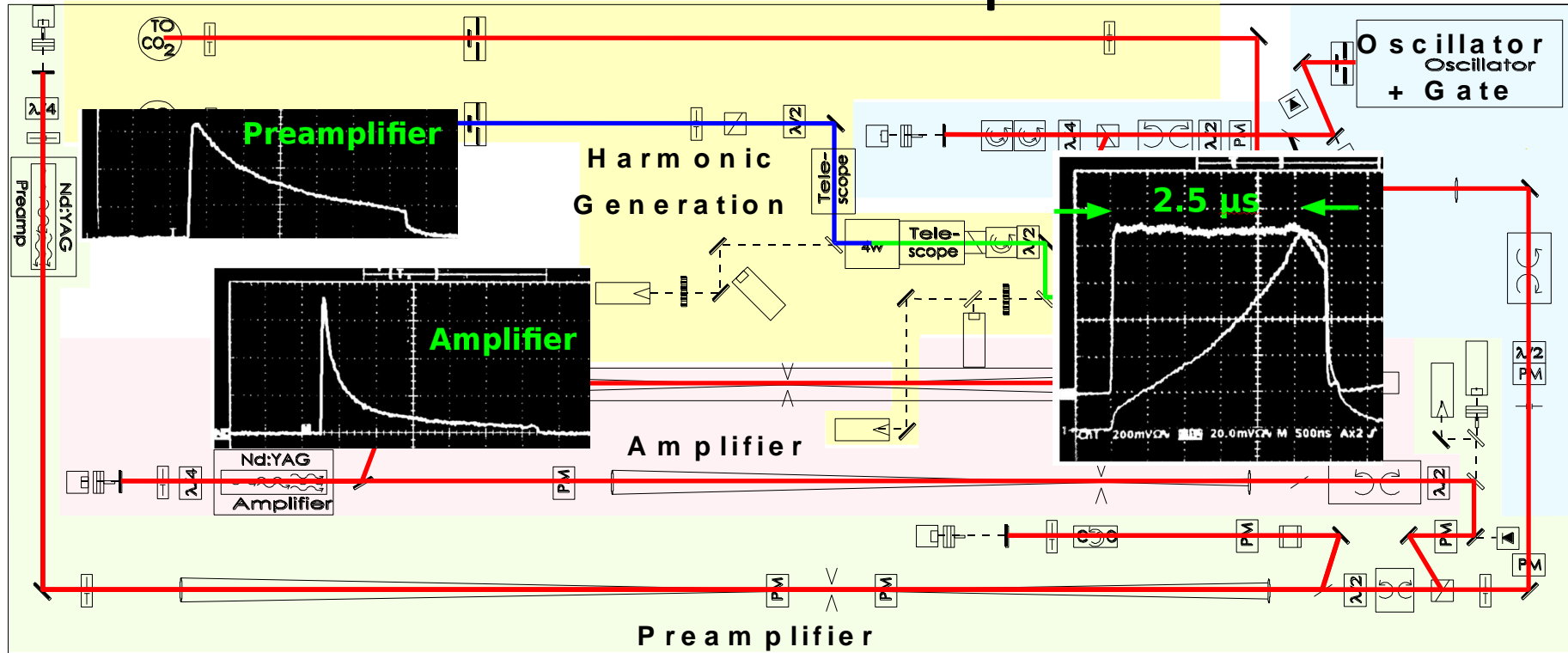
Gun Drive Laser: Relocation

- Ti:Sapphire drive laser will be first system in ATF II / Bldg. 912
- Will operate in new cleanroom in for UED experiment mid-2015
- ATF II Linac construction will occur as laser is operating
- Beam transport to gun to be in place for linac commissioning (~2017)

Nd:YAG System Overview

- Provides valuable backup system
- Could be used in combination with Ti:Sapphire for dual, triple pulse generation from gun, e.g. independently timed witness bunches at arbitrary delays
- Has been exclusively used for laser cathode cleaning – well defined laser parameters

Linac Pulse Train Operation



- Novel laser architecture mitigates gain depletion throughout pulse train & operates in conjunction with RF feedforward
- Demonstrated & used extensively in FEL oscillator experiment ca. 1997, and again in 2011-2012 for Radiabeam ICS experiment
- Produce up to 200 pulses flat within 5%

Nd:YAG Legacy Performance

- Reliable, high-availability operation
- Fast turn-on, limited “tweaking” from laser physicists day-to-day

<u>Energy: (dual pulse mode)</u>		<u>Transverse Distribution:</u>	
UV on cathode	0-30 mJ x 1 pulse	Range of beam size on cathode (\emptyset)	0.2 - 3 mm
IR to CO2 laser	10 mJ x 2 pulses	Top-Hat Beam Profile Modulation (P-P)	<50%
Laser output: total IR	30 mJ		
IR to gun	7.5 mJ	<u>Repetition rate</u>	1.5, 3 Hz
Green	2.5 mJ		
UV	500 mJ	<u>Shot-to-shot stability (rms):</u>	
		Timing	<0.2 ps
<u>Energy: (pulse train mode) IR</u>	<u>~100 mJ / 20 pulses</u>	Energy	<0.8 %
		Pointing (fraction of beam \emptyset)	<0.3 %
<u>Pulse duration (FWHM):</u>			
Oscillator IR	7 ps	<u>Drift (8 hour P-P)</u>	
Amplified IR	14 ps	Timing	<15 ps
Green	10 ps	Energy	<5%
UV	8 ps	Pointing (fraction of beam \emptyset)	<1%

Nd:YAG: Relocation plan

- Nd:YAG is entrenched in Bldg. 820, and replacement now is too inefficient
- Therefore, it will remain at ATF I until experiments there terminate (~2017)
- Logistics of additional laser room need to be coordinated with laser move to Bldg. 912

NIR Strong Field Laser: Motivation

- Experiments at ATF II will benefit from a NIR laser system:
 - in addition to 10 μm CO_2 laser to access underlying physics, e.g. two-color Compton
 - as a key diagnostic for characterizing interactions, e.g. Ion acceleration interferometry
- A dedicated high power Ti:Sapphire laser is planned to satisfy such needs
- Mechanical, timing, beam transport, and utilities infrastructure being designed to support additional laser system

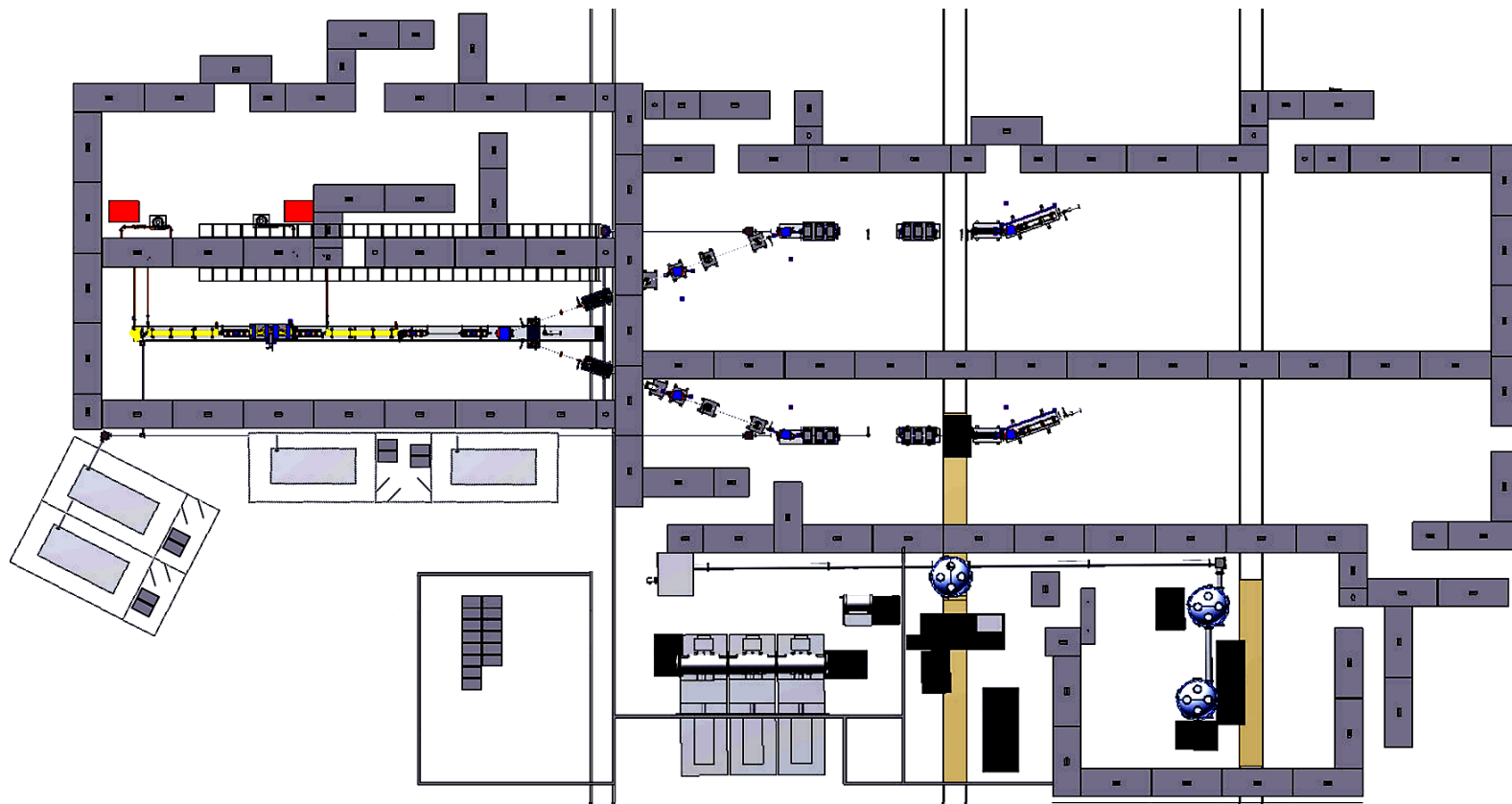
NIR Strong Field Laser - Components

- Will be seeded by small pickoff from existing Ti:Sapphire drive laser (optical synchronization)
- Achieve contrast enhancement via XPW
- Inject into flashlamp-pumped CPA system tested at BNL Instrumentation division
- Initially expect 150 mJ final output
- Pulsewidth is oscillator dependent: 50-180 fs \Rightarrow 1 TW initially
- Additional amplifier stage and grating compressor could allow 10 TW if needed

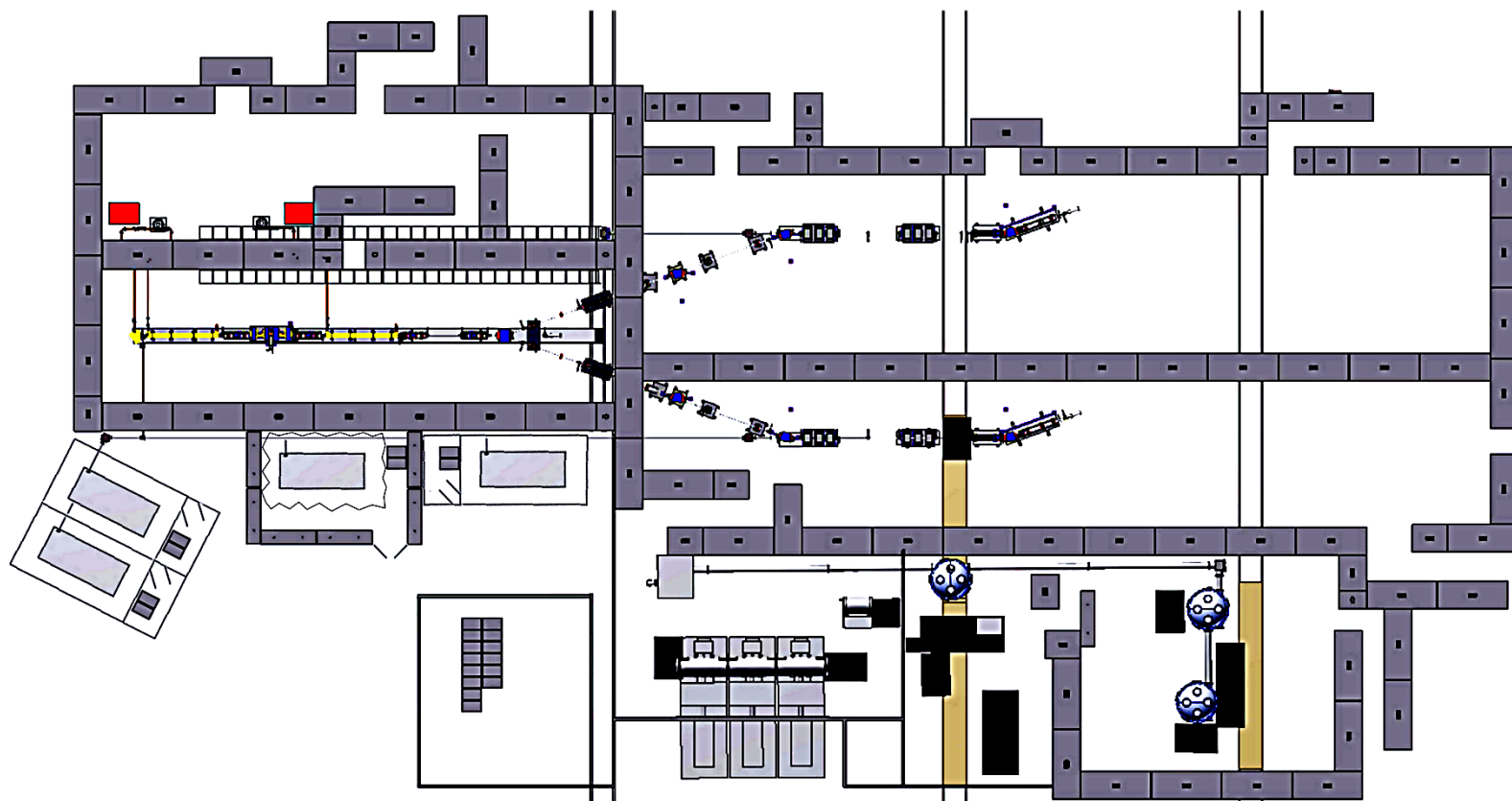
NIR Strong Field Laser: Relocation

- Ti:Sapphire drive laser will be first system in Bldg. 912
- Additional laser room will be constructed alongside linac beamlines
- Laser transport lines will enable transport between rooms and BL#1

Laser Siting Concepts



Laser Siting Concepts



Conclusion

- Broad range of laser capabilities already planned and available for ATF II
- 100 TW CO₂ laser will debut in ATF, with peak power increases already underway at ATF I
- Significant flexibility will be designed into facility
- Exact implementation can be adjusted now and for some time to come